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TITLE: COMPUTER BASED TERRAIN ANALYSIS FOR OPERATIONAL PLANNING

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Computer Based Terrain Analysis for Operational Planning

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Abstract

Analysis of operational capability is an ongoing task for military commanders. In peacetime, most analysis is conducted via computer based combat simulations, where selected force structures engage in simulated combat to gain insight into specific scenarios. The command and control (C^2) mechanisms that direct combat forces are often neglected relative to the fidelity of representation of mechanical and physical entities. C^2 capabilities should include the ability to plan a mission, monitor execution activities, and redirect combat power when appropriate. This paper discusses the development of a computer based approach to mission planning for land warfare. The aspect emphasized is the computation and representation of relevant terrain features in the context of operational planning.

Introduction

Combat simulations have been used over the last two decades to aid in the analysis of complex military issues. Such simulations must represent the physical processes involved and the human decision making that affects the physical activities. The representation of physical processes is usually quite good, whereas the human decision making is often less well modeled. Most of the planning measures that are used in simulations is performed by analysts prior to the execution of the computer code. Interpretation of mission and the disposition and movement of forces is planned in the scenario development phase. Thereafter, in plan execution, units will react to enemy forces according to tactical decision rules. These rules essentially govern a reactive mode of unit behavior. In addition to tactical decision rules, other approaches have been used to represent the decision making element of combat [1], but still provide only a local measure of control rather than a global capability to assess the situation and replan, if necessary, to meet a new situation. The failure to develop a global command and control structure is due more to the inadequacy of the modeling tools rather than the lack of effort.

At Los Alamos National Laboratory a long term project has been initiated to embed a dynamic planning and execution monitoring capability within a combat simulation. The goal of the initial phase of the project is to emulate the operations planning process performed by brigade staff. One characteristic of operational planning problems is that typically an acceptable solution is sought rather than the optimal solution. Thus the goal of the project is to develop "reasonable" plans, on the order of quality that a recent graduate of the U.S. Army Command and General Staff College (CGSC) would produce. The plans would be developed autonomously by the program, but the results would be subject to review and modification by an analyst before simulating plan execution.

Planning

The operational planning process is well defined [2] and has been the subject of several computerization efforts [3-8]. The overall process, as taught at CGSC, is shown in Figure 1. This description of the planning process is fine for humans, for it stresses the cognitive and associative memory capabilities of the mind; for a oriented description of the planning activity. A mission, defined as a set of essential tasks, is input. These tasks are to be executed within the operational area, a bounded set of terrain assigned to the combat unit. The unit is assigned resources, maneuver and support elements which will fight the battle. Also, the terrain is populated with enemy units attempting to achieve their own, possibly unknown, mission. These are the basic domain elements: mission, enemy, terrain, and troops. The logical manipulation of these domain elements to produce an operational plan is guided by doctrine - a set of guidelines, rules, heuristics, or techniques that provide partial specifications of plans given certain conditions. Human planners, by applying doctrine to the planning domain elements, derive operational plans. Thus emulation of the planning process via computer requires a representation of the domain elements, and of the relationships between and operations on the domain elements. Computer based terrain analysis applies to the former.

Terrain Analysis

Terrain analysis attempts to completely describe the area of operations in militarily significant terms. The evaluation of the military value of terrain can be from several perspectives. The doctrinal perspectives at brigade level are observation and fields of fire, cover and concealment, obstacles, key terrain, and avenues of approach (OCOKA). Observation and fields of fire are based on visibility conditions and effective weapon ranges. Cover is protection from observation and fire; concealment is protection from observation. These perspectives involve terrain roughness, slope, vegetation, man-made, and natural features. Obstacles are natural or man-made features that slow, stop, or deflect movement of combat units. Examples of obstacles are large rivers, railroad embankments, tank traps, and minefields. Key terrain is any area whose seizure or control offers significant advantage to the possessor. Avenues of approach are routes that enable a unit to reach its destination, key terrain, or objective. Avenues of approach should have adequate maneuver space and provide access to adjacent avenues. Avenues of approach contain mobility corridors which are areas that permit movement and maneuver for lower echelon units, e.g. battalions and companies.

Computer Based Terrain Analysis

While computerized analysis of terrain is not a new idea, the processing involved typically generates particular perspectives which are presented to the analyst for interpretation [6,7]. In contrast, this approach uses the object oriented programming paradigm [9] to represent classes of terrain objects, and subsequently process the terrain data to instantiate class members. An object is a software data structure that can contain both declarative and procedural data. A message passing protocol is used as a control structure and often hierarchical object relations with inheritance are supported. This approach provides the representational power to enable interpretation of the terrain by the computer. Commonly used features are represented as object classes. Each class is described in terms of attributes and activities that characterize members of the class. For example, an obstacle hinders mobility, and has attributes that describe the extent and nature of the obstacle. It can also have an activity that specifies how the mobility is degraded. This type of representation provides a better associative link between the features a planner encounters in the domain and the data elements used by the planning program. The instantiation of terrain objects gives a mixed quantitative, qualitative, and procedural description of the object that forms the basis of reasoning process in the computer planner. By giving a more precise and accurate description of a terrain feature than the qualitative impression an analyst can get from a map, the instantiated object becomes a significant aid to the analyst.

To define the terrain object classes, [2] is used as a reference. A partial set of terrain classes is described here; other classes can be created as necessary. Interestingly, there exists a procedural dependency among the classes, which is illustrated in Figure 3. In this graph, each level depends on the availability of the lower level, with the lowest level, the raw terrain data and the direction of movement, used as the initial input. The exception is the top level, objectives, which are given in the mission statement. The second lowest level contains the three basic terrain types: No-Go, Slow-Go, and Go. The definitions of these terrain types depend upon the kind of unit that will traverse the terrain, either infantry or mechanized forces. The definitions given here relate to mechanized units.

The No-Go terrain class consists of terrain that significantly hinders movement. It is characterized by built up urban areas wider than 500 meters; waterways that cannot be forded or spanned; slopes of 45 percent or greater uphill; elevation variations of more than 200 meters per kilometer; man-made or military obstacles; trees greater than six inches thick or less than 20 foot spacing; or zero hard surface roads per kilometer. Slow-Go terrain also hinders ground movement, but to a lesser degree than No-Go. It is characterized by waterways that can be forded or spanned in several places; slopes of 30 to 45 percent uphill; trees 2-6 inches thick with less than 20 foot spacing; elevation variations of 100-200 meters per kilometer; or one hard surface road and one trail per kilometer, or two trails per kilometer. Go terrain is fairly open terrain with no hindrance to ground movement. It is essentially the terrain that remains after No-Go and Slow-Go terrain has been defined. However, it is characterized as waterways that can be forded anywhere along their length; slopes less than 30 percent; trees less than two inches thick or with spacing greater than 20 feet; elevation variations less than 100 meters per kilometer; or two or more hard surface roads per kilometer.

Obviously for a computer to use the above definitions to class terrain, a fairly complete description of surface and cultural features is needed. Table I lists the terrain attributes available in a 97.1 by 125.1 kilometer region near the inter-German border. Terrain resolution is 100 meters. In addition to these, other needed attributes can be computed and are listed in Table II. Given these attributes it is straightforward to determine No-Go, Slow-Go, and Go terrain on a point by point basis. Adjacency criteria are applied to aggregate similar terrain points into clusters that represent instantiations of the parent terrain class. One set of criteria used for clustering is to assign the point its own terrain type if it has K neighbors of the same type; otherwise the point is given the terrain type of the majority of its neighbors. Figure 4 illustrates this rule for K=1.

Mobility corridors are relatively open areas that permit movement and maneuver from an initial point to an objective or key terrain. The size of a mobility corridor is a function of the size of unit that will use it, as specified in Table III. To create a mobility corridor, the terrain grid is considered to be a weighted graph. Each node (not on the border) in the graph is connected to each of its eight neighbors. The edge connecting a node with a neighboring node has a weight associated with it corresponding to the "cost" of travelling to that node. The computation of the edge weight is performed by the Combat Maneuver Model, a derivative of the Army Mobility Model [10]. However, additional cost is added to the edge weight if the source or destination node is No-Go or Slow-Go terrain. Hence, the problem is now to find the minimum cost traversal from a set of initial departure points to a set of final objective points. If k is the number of edges in the graph, Dijkstra's algorithm [11] computes a solution in $O(k*k)$ time. By enhancing Dijkstra's approach with adjacency lists to retain intermediate information, the solution is computed in $O(k*\log(k))$ time. This approach only provides a path one grid wide, e.g. 100 meters. By using a weighted average of the edge weights in a neighborhood of a node, a "corridor" of arbitrary width can be determined. However, other methods of computing the width of mobility corridors are under development and may be better suited to representing the terrain extent of a mobility corridor.

Two or more mobility corridors are combined to create an avenue of approach. The derivation of avenues of approach from mobility corridors is based on the distance between corridors given in Table IV. The distance metric between mobility corridors is derived from the least cost paths that form the center line of the corridors. It is computed as the average minimum distance from points on one path to the second path. The number of mobility corridors that make up an avenue of approach is an indication of the width and maneuver space for that approach to the objective. Other factors influence the desirability of an avenue, the number of high speed approaches, e.g. hard surface roads, the areas of canalization, the number and placement of obstacles, the length of the avenue, and the influence of surrounding terrain.

The terrain in and around an avenue of approach may have the potential to significantly influence the conduct of operations through that avenue. Terrain that achieves this potential is termed key terrain and is characterized by line of sight (Bresenham's algorithm) to the trafficable segments of the avenue at effective weapon (direct fire) engagement ranges. Other applicable factors include access routes to the terrain, the size of the area, plus concealment and cover for the weapon emplacement positions. Computationally, key terrain is determined by examining how visible the mobility corridors in the avenue are from terrain within direct fire weapon range, nominally three kilometers. Figure 5 illustrates the process. The line of sight requirement typically implies an elevated area bounding one or more mobility corridors, so the key terrain algorithm initially searches for areas exceeding the median elevation for the neighborhood. Contiguous areas of "higher" elevation with a minimum 500 meter extent are selected for line of sight testing. For each point in the test area, the portion of the avenue of approach visible from the point is computed. This is compared to the portion of the avenue of approach within nominal weapon range. If a significant fraction of the avenue of approach is visible from the test area, the area is designated as potential key terrain. Subsequent tests are applied to ensure access to the area and availability of concealment. Areas that meet all test criteria are designated key terrain.

Certain key terrain may be designated as intermediate objectives, but this determination cannot be done on the basis of terrain alone. Intermediate objectives are often assigned to mass forces prior to crossing major obstacles, key terrain that controls high speed avenues of approach or significant intersections of mobility corridors. However, intermediate objectives are derived from the knowledge of the mission and an understanding of the relationships among mobility corridors, key terrain, obstacles, and enemy disposition. Thus only a small set of candidates for intermediate objectives can be created based solely on terrain criteria.

Mobility corridors, avenues of approach, key terrain, and intermediate objectives have less rigorous definitions than the No-Go and Slow-Go classes. Hence it is imperative to validate the class descriptions. To do this, experienced Army officers with CGSC experience review the class descriptions. Test cases are run to compare instantiations of class members with the officer's analysis of a military map of the region for correspondence of relevant features. This is relatively easy as officers are trained to mark clear acetate sheets overlaid on the map. Obstacles, No-Go terrain, mobility corridors, intermediate objectives, and pertinent control measures are placed on the overlay. Deviations between a computer-generated and an officer-generated feature are analyzed and the computer algorithm is modified to reduce the differences

Conclusion

Computer based terrain analysis has been presented as an essential element of developing a computer based operational planning capability for combat simulations. The described process uses an object oriented approach to represent the terrain features used in planning as described by relevant Army instructional texts. Also the computational procedures used to instantiate members of terrain object classes are described. The terrain analysis procedures developed constitute a significant aid to analysts in developing scenarios for combat simulations, and the representation developed is appropriate as a basis for reasoning about terrain in a computer based planning program.

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Terrain Attributes from Database

Elevation	meters
Vegetation Height	meters
Urban	none, present
Hydrology	none, fordable river, non-fordable river, lake
Soil Type	muskeg, fine grained, coarse grained, ch
Power Lines	none, present
Bridges	none, present
Land Use Code	open water, cropland, pasture, coniferous forest, deciduous forest, forest clearing, orchard or vineyard, dense brushland, open brushland, wetlands, peat cuttings, abandoned agriculture, bare ground or sand dunes, surface mines, urban
Road Type	none, autobahn, primary, secondary, trail
Obstacles	none, embankment or ditch, wall or fence, other manmade, military

Table I

Other Computed Terrain Attributes

Elevation Variation per km	meters
Slope	percent
Urban Buildup	none, 500 m wide or more
Number of Hard Surface Roads per km	integer
Number of Trails per km	integer
Stem Diameter and Spacing	diameter < 2" or spacing > 20" 2"<diameter<6" and spacing < 20' 6"<diameter and spacing < 20'

Table II

Widths of Mobility Corridors

Unit	Width
Division	6.0 kilometers
Brigade or Regiment	3.0 kilometers
Battalion	1.5 kilometers
Company	0.5 kilometers

Table III

Maximum Distance Between Mobility Corridors

Avenues of Approach	Mobility Corridor	Maximum Distance
Division	Brigade or Regiment	10 kilometers
Brigade or Regiment	Battalion	6 kilometers
Battalion	Company	2 kilometers

Table IV

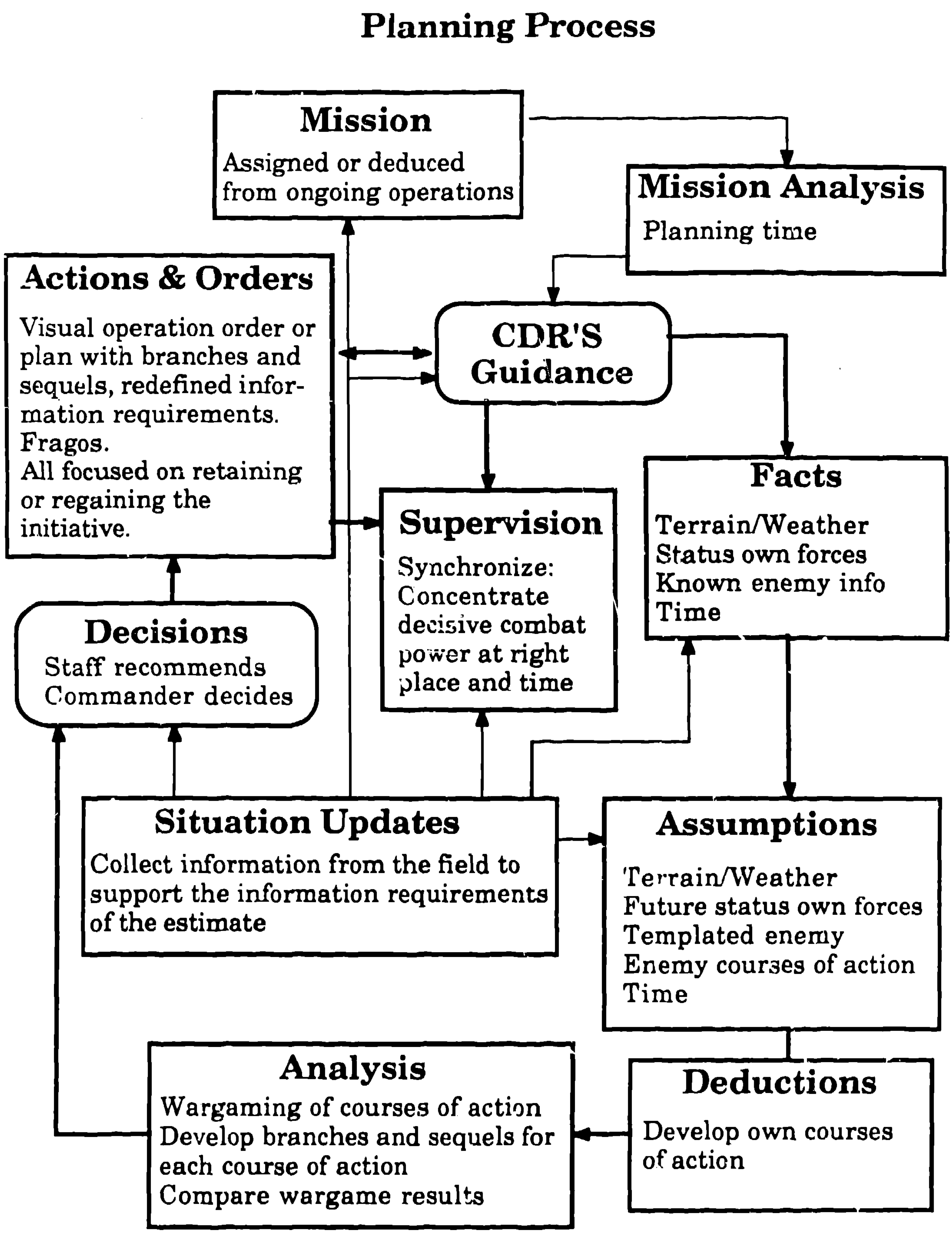

Figure 1. Operational Planning

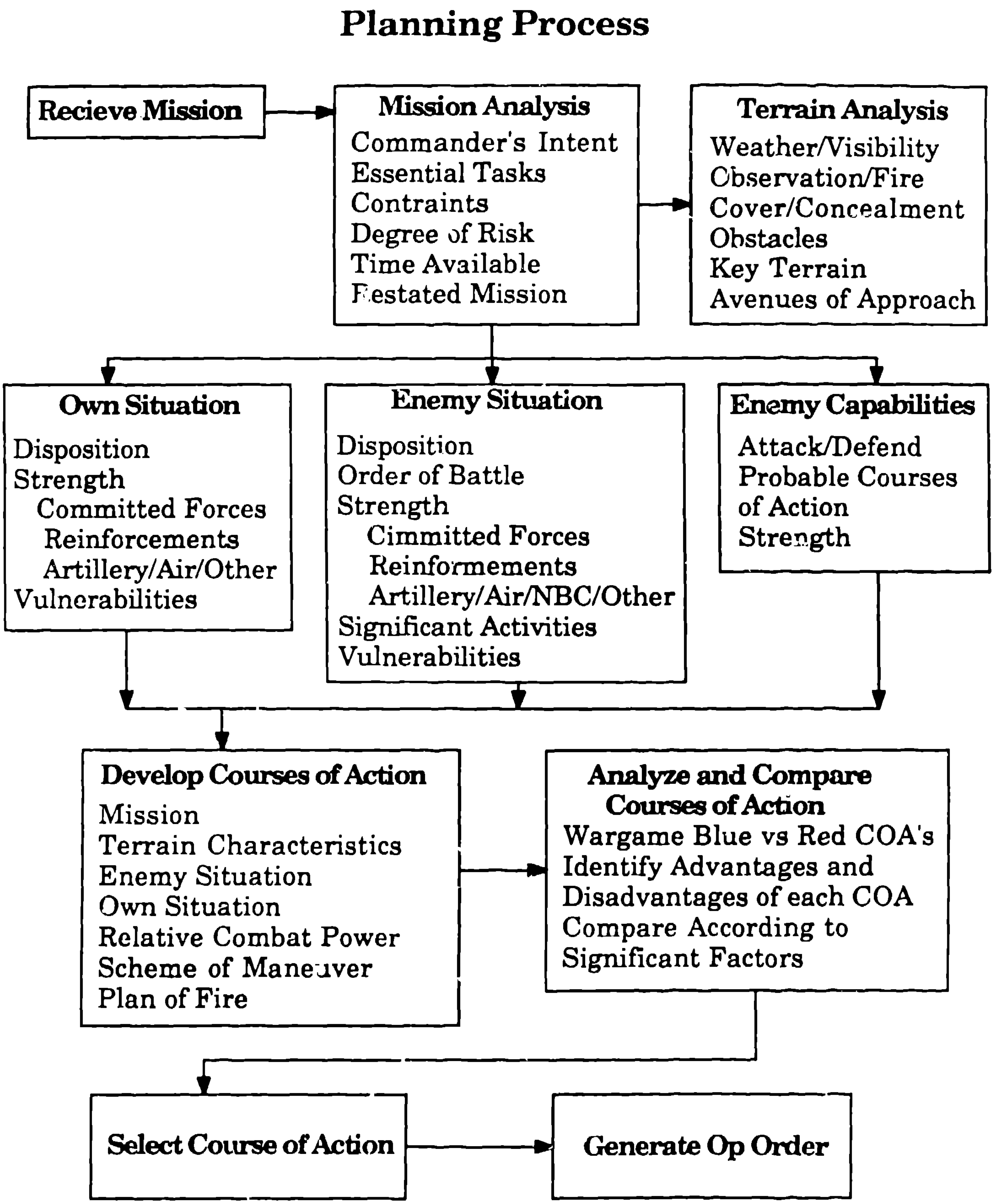

Figure 2. Process oriented view of operational planning.

Terrain Object Classes

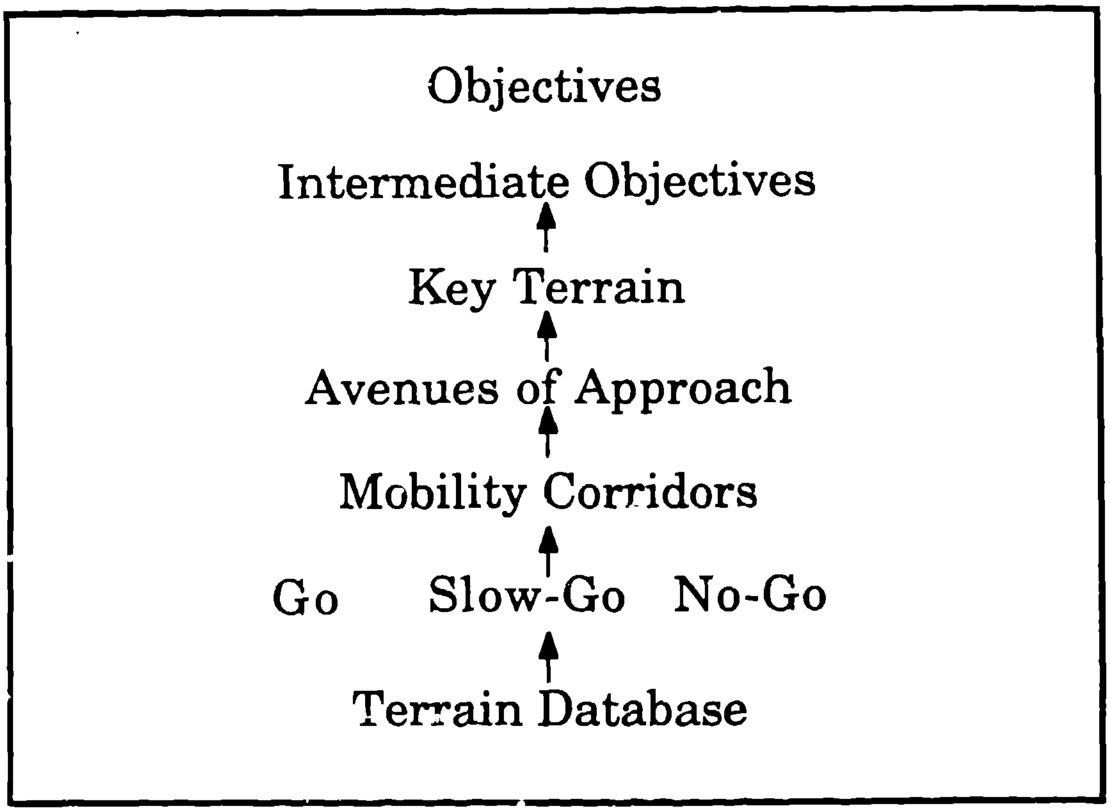

Figure 3. Procedurally dependent relation of terrain classes.

Terrain Aggregation

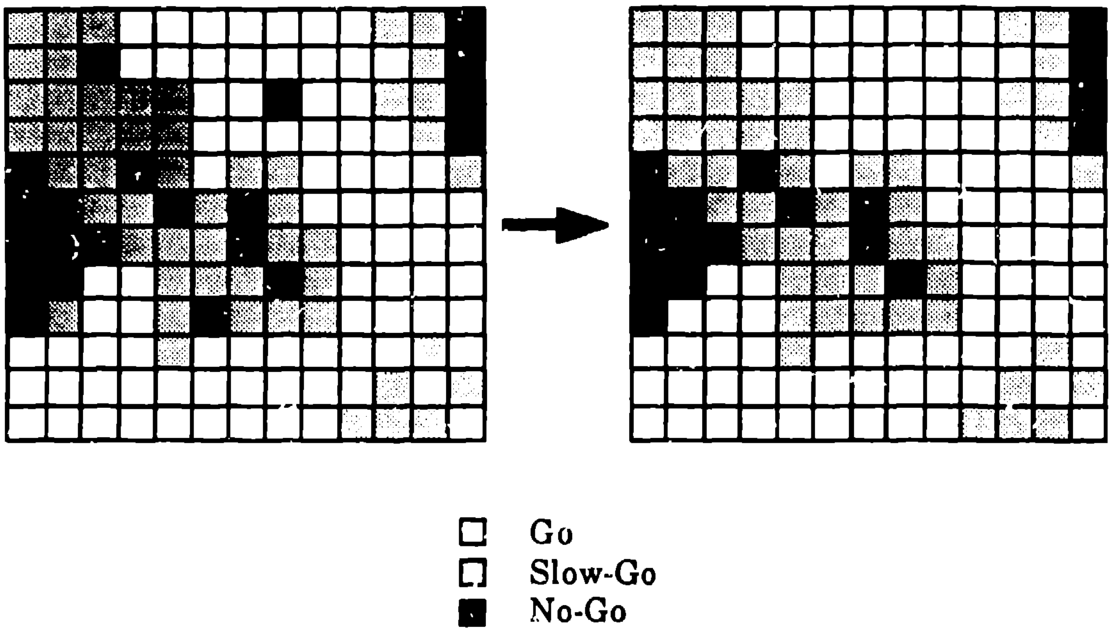

Figure 4. Aggregation of terrain types according to the single neighbor criterion.